NANOWIRES-BASED TRANSPARENT CONDUCTORS

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application is a divisional of U.S. patent application Ser. No. 11/504,822 filed Aug. 14, 2006, now pending; which claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application No. 60/707,675 filed Aug. 12, 2005, U.S. Provisional Patent Application No. 60/796,027 filed Apr. 28, 2006, and U.S. Provisional Patent Application No. 60/798,878 filed May 8, 2006; all of these applications are incorporated herein by reference in their entireties.

BACKGROUND

[0002] 1. Technical Field

[0003] This invention is related to transparent conductors and methods of manufacturing the same, in particular, to high-throughput coating methods.

[0004] 2. Description of the Related Art

[0005] Transparent conductors refer to thin conductive films coated on high-transmittance insulating surfaces or substrates. Transparent conductors may be manufactured to have surface conductivity while maintaining reasonable optical transparency. Such surface conducting transparent conductors are widely used as transparent electrodes in flat liquid crystal displays, touch panels, electroluminescent devices, and thin film photovoltaic cells, as anti-static layers and as electromagnetic wave shielding layers.

[0006] Currently, vacuum deposited metal oxides, such as indium tin oxide (ITO), are the industry standard materials to provide optically transparency and electrical conductivity to dielectric surfaces such as glass and polymeric films. However, metal oxide films are fragile and prone to damage during bending or other physical stresses. They also require elevated deposition temperatures and/or high annealing temperatures to achieve high conductivity levels. There also may be issues with the adhesion of metal oxide films to substrates that are prone to adsorbing moisture such as plastic and organic substrates, e.g. polycarbonates. Applications of metal oxide films on flexible substrates are therefore severely limited. In addition, vacuum deposition is a costly process and requires specialized equipment. Moreover, the process of vacuum deposition is not conducive to forming patterns and circuits. This typically results in the need for expensive patterning processes such as photolithography.

[0007] Conductive polymers have also been used as optically transparent electrical conductors. However, they generally have lower conductivity values and higher optical absorption (particularly at visible wavelengths) compared to the metal oxide films, and suffer from lack of chemical and long-term stability.

[0008] Accordingly, there remains a need in the art to provide transparent conductors having desirable electrical, optical and mechanical properties, in particular, transparent conductors that are adaptable to any substrates, and can be manufactured and patterned in a low-cost, high-throughput process.

BRIEF SUMMARY

[0009] In one embodiment, it is described herein a transparent conductor comprising: a substrate; and a conductive layer on the substrate, the conductive layer including a plurality of nanowires, preferably, metal nanowires.

[0010] In another embodiment, a transparent conductor comprises a substrate; and a conductive layer on the substrate, the conductive layer including a plurality of metal nanowires embedded in a matrix, in particular, an optically clear polymeric matrix.

[0011] In yet another embodiment, the transparent conductor further comprises a corrosion inhibitor.

[0012] In a further embodiment, it is described herein a method of fabricating a transparent conductor comprising: depositing a plurality of metal nanowires on a substrate, the metal nanowires being dispersed in a fluid; and forming a metal nanowire network layer on the substrate by allowing the liquid to dry.

[0013] In another embodiment, a method comprises depositing a plurality of metal nanowires on a substrate, the metal nanowires being dispersed in a fluid; and forming a metal nanowire network layer on the substrate by allowing the liquid to dry; depositing a matrix material on the metal nanowire network layer; and curing the matrix material to form a matrix, the matrix and the metal nanowires embedded therein forming a conductive layer.

[0014] In a further embodiment, the method described herein can be performed in a reel-to reel process, wherein the substrate is driven by a rotating reel along a traveling path, and the depositing of the metal nanowires is carried out at a first deposition station along the traveling path, and the depositing of the matrix material is carried out at a second deposition station along the traveling path.

[0015] In another embodiment, the conductive layer can be patterned, in particular, photo-patterned by using photo-curable matrix materials.

[0016] In another embodiment, it is described herein a laminated structure comprising: a flexible donor substrate; and a conductive layer including a matrix embedded with a plurality of metal nanowires.

[0017] In a further embodiment, a laminating process is described, the process comprising: applying the laminated structure to a substrate of choice, and removing the flexible donor substrate.

[0018] In yet another embodiment, a display device is described, the display device comprising at least one transparent electrode having a conductive layer, the conductive layer including a plurality of metal nanowires. In particular, the conductive layer comprises the metal nanowires in an optically clear polymeric matrix.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0019] In the drawings, identical reference numbers identify similar elements or acts. The sizes and relative positions of elements in the drawings are not necessarily drawn to scale. For example, the shapes of various elements and angles are not drawn to scale, and some of these elements are arbitrarily enlarged and positioned to improve drawing legibility. Further, the particular shapes of the elements as drawn are not intended to convey any information regarding the actual shape of the particular elements, and have been selected solely for ease of recognition in the drawings.

[0020] FIG. **1** is a schematic illustration of a nanowire.

[0021] FIG. **2** is a graph illustrating the expected optical properties of a silver nanoellipsoids at various wavelengths of light.

[0022] FIG. **3** illustrates the absorption spectrum of a silver nanowire layer on a polyethylene terephthalate (PET) substrate.

[0023] FIG. **4** is a graph illustrating expected values for various resistivity properties of a nanowire based on the wire diameter.